

# Sequential cropping of Vertisols in the Ethiopian highlands using a broadbed-and-furrow system

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(Accepted for publication in April 1989)

## SUMMARY

IN A TRIAL conducted at ILCA's research station in Debre Zeit, in the Ethiopian highlands, wheat was planted on broadbeds early in the main rainy season and chickpea at the beginning of the dry season.

Chickpea plots were subjected to four irrigation treatments (no irrigation; irrigation at planting; irrigation at planting and 35 days after planting; and irrigation at planting, 35 days and 70 days after planting). Water was supplied through furrows until the top 10 cm of the broadbeds were saturated. Soil–water tension at 10 and 30 cm depth was measured to determine its effect on plant height, 1000-seed weight, and grain and straw yields of chickpea.

At 10 cm depth, soil–water tension differed significantly ( $P < 0.05$ ) between treatments. During the first 13 days of the trial, the 10-cm soil–water tension on control plots (without irrigation) was high enough to prevent seed germination. At 30 cm depth, the tension on control plots was significantly higher than on plots irrigated at planting, but after the second irrigation, soil–water tension was significantly higher on irrigated plots than on control plots.

Chickpea plants on plots with one irrigation were shorter and bushier than those on plots irrigated two or three times. Grain yield and 1000-seed weight from plots with one irrigation were higher than those from plots irrigated three times, but there were no differences in straw yield between treatments.

The trial showed that with a starter irrigation to aid the germination of a second crop, sequential cropping of two crops in the same growing season is feasible in the Debre Zeit area.

## INTRODUCTION

Vertisols are agriculturally important soils in the Ethiopian highlands but because of waterlogging in the main rainy season, their potential for cropping is not fully realised. These soils are found mostly on land with less than 8% slope and have clay contents of 35 to 80%. Traditionally, many Vertisol crops are planted towards the end of the main rainy season and grow on residual moisture (Abate Tedla et al, 1988).

The productivity of Vertisols can be increased by surface drainage. Broadbeds and furrows (BBFs) made with low-cost, animal-drawn implements help drain excess water (Jutzi et al, 1986), thus enabling farmers to plant crops early in the main rainy season. Run-off rainwater can be conserved in ponds or reservoirs (Abiye Astatke et al, 1986) and used to irrigate the land for a second crop. Production of both human food and animal feed can thereby be increased.

The effects of improved surface drainage on the productivity of Vertisols were investigated in a wheat-and-chickpea cropping trial conducted in 1987 at ILCA's Debre Zeit research site in the Ethiopian highlands.

## MATERIALS AND METHODS

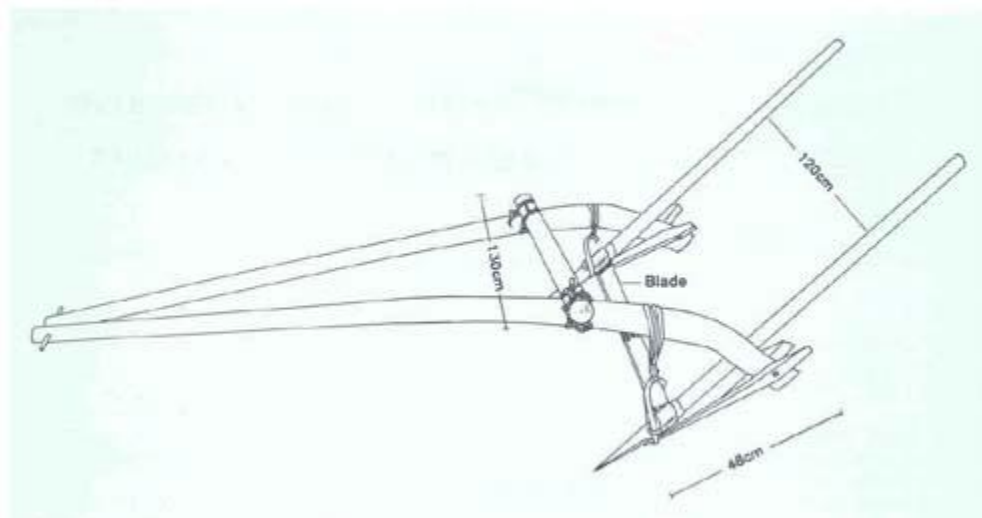
A 50 × 60 m field sloping gently (0.4% slope) along its shorter side was used for the trial. Wheat was planted on the field in uniform stands early in the rainy season, and after its harvest, the same field was cultivated under chickpea with four different irrigation treatments.

The seedbed was prepared by cultivating the field three times with the traditional plough (*maresha*). On 12 June 1987, Durum wheat (*Triticum durum* Buhae) and diammonium phosphate were broadcast on the field, at the rate of 120 kg/ha and 100 kg/ha respectively. Broadbeds and furrows were then made using an ox-drawn broadbed maker. During this operation, seed and fertilizer were covered.

The broadbeds were formed down the slope, and were 50 m long and 1.2 m wide from mid-furrow to mid-furrow. In all, 50 broadbeds were made across the 60-m wide trial field, the two on the outside serving as borders.

Wheat was harvested on 12 September 1987. Six days later, on 18 September, the topsoil of the broadbeds was disturbed to about 3 cm depth with a blade harrow attached to the broadbed maker (Figure 1), to destroy weeds. On 2 October 1987, chickpea (*Cicer arietinum*, Desi type) was planted on 48 broadbeds at the rate of 80 kg seed/ha. The blade harrow was also used to cover the seed.

**Figure 1.** Blade harrow attached to the broadbed maker.



The general climatic conditions during the chickpea irrigation trial are shown in Table 1. Total rainfall over the trial period was negligible, while evaporation was moderate and radiation ample for crop growth. The average air temperature during the trial was 20.7°C (range 6.2–30.1°C).

**Table 1.** Total monthly rainfall, radiation and evaporation. Debre Zeit, Ethiopia, October 1987–January 1988.

Month	Rainfall (mm)	Radiation (MJ)	Evaporation (mm)
October	5.0	973.7	47.3
November	0.0	972.3	59.4
December	0.4	957.6	53.4
January	4.4	714.8	58.4

Four irrigation treatments were applied, each with three replicates. The treatments were:

Treatment 1. No irrigation (control).

Treatment 2. Irrigation at planting (2 October 1987).

Treatment 3. Irrigation at planting and 35 days after planting (5 November).

Treatment 4. Irrigation at planting and 35 and 70 days after planting (10 December).

Treatments were randomised as shown in Figure 2. Each treatment plot had four broadbeds. Five furrows were used to water the four broadbeds. The furrows (0.4% average slope) were blocked at the lower end to raise the level of water sufficiently high to wet the top of the beds.

Tensiometers<sup>1</sup> were set at three points along the third broadbed of each plot in the first and third replications. The outer broadbeds of each plot were kept as borders to prevent spill-over effects between treatments. At each of the three points, three tensiometers were set at 10 cm depth and three at 30 cm depth. They were placed in the middle of the bed, with the outer tensiometers 10 cm from the edge of the bed.

<sup>1</sup> A tensiometer is an instrument which directly measures soil–water tension.

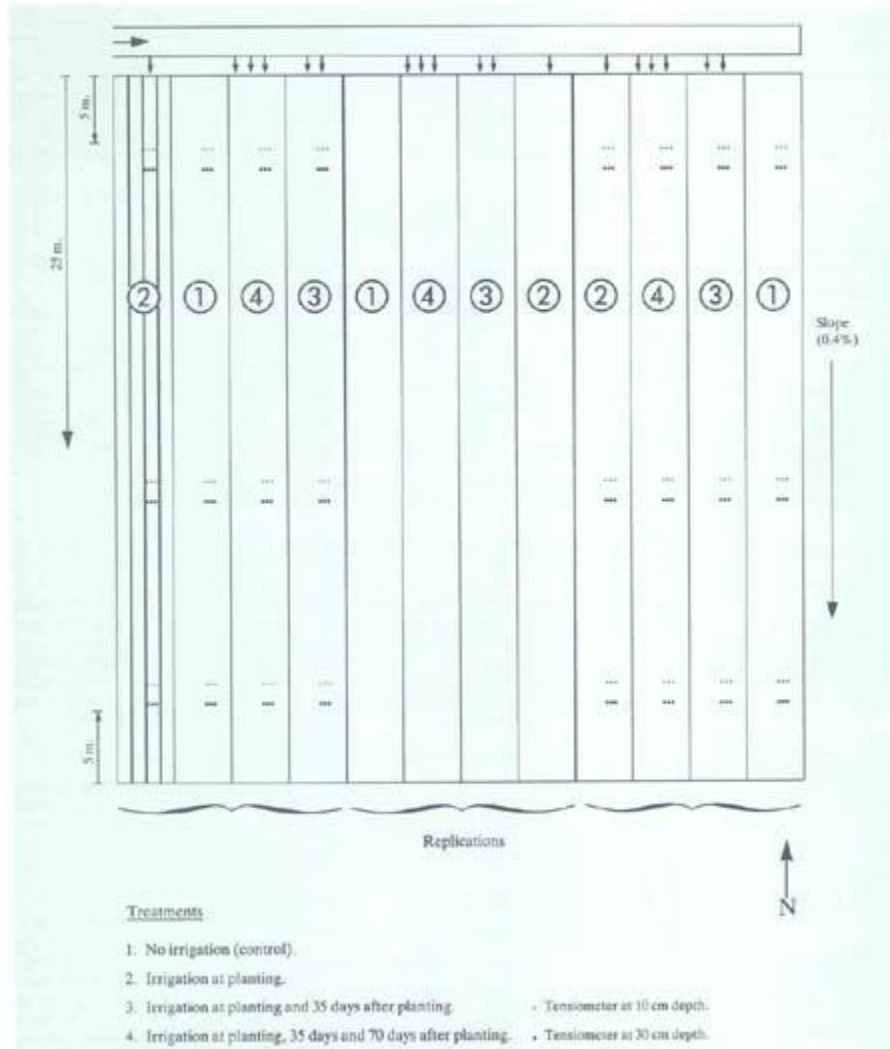
Water was applied until the top 10 cm of soil were saturated, i.e. soil–water tension was 0. On average, 30.8 m<sup>3</sup> of water per plot, or 1280 m<sup>3</sup>/ha, was required to saturate the top 10 cm of soil in the first and third irrigations. During the second irrigation, saturation was achieved with only 670 m<sup>3</sup> water/ha.

The tensiometers were read daily at 0900 hours. Readings taken during the first 8 and 13 days after irrigation at planting, during the first 5 and 10 days after each subsequent irrigation, and all readings between irrigations, were analysed. In addition, soil samples were taken weekly from 0–10, 10–25 and 25–50 cm soil layers after the start of irrigation. Four samples were taken from each layer in each treatment plot, and soil moisture content was determined gravimetrically.

Two weeks before harvesting the chickpea, six plants were selected at random in each treatment and their heights were measured. A sample area of 108 m<sup>2</sup> on the two central broadbeds in each plot was harvested at the end of January to determine grain and straw (DM) yields. Grain yield was adjusted to 10% moisture content and 1000-seed weights were determined.

Data were analysed using the Statistical Analysis System package (SAS Institute, 1987). The model used to analyse soil-water tension included the fixed effects of replicates and treatments,

**Figure 2.** Layout of a chickpea irrigation trial, Debre Zeit, Ethiopia.



Note: Soil-moisture tension was measured in the first and third replications only.

## RESULTS

## Time spent on cultivation and bed reshaping

**Wheat.** The preparation of the seedbed for the wheat crop required three passes with the *maresha*. The first pass, made at the end of April, required 42 hours/ha to complete. The second and third passes, made at the beginning of June, took 38 and 30 hours/ha respectively. Covering the seed and fertilizer needed two passes with the broadbed maker, which together took 11 hours/ha. Seedbed preparation and seed covering for the wheat crop thus required 121 ox-pair hours per hectare.

*Chickpea.* After the wheat harvest in mid-September 1987, four passes were made with a blade harrow mounted on the broadbed maker: two on 18 September, which together required 17 hours/ha, and two on 22 September, which together took 13 hours/ha to complete. Seed was covered by a single pass with the blade harrow, which required 11 hours/ha. The total time spent on bed reshaping and covering the chickpea seed was, therefore, 41 hours/ha.

## Soil conditions

*Soil–water tension.* During the first 13 days after irrigation at planting (treatment 2), the soil–water tension of irrigated plots was significantly ( $P < 0.05$ ) lower than that of the control plots at both 10 and 30 cm depth (Table 2). There was also a significant ( $P < 0.05$ ) difference between treatments in the 30-cm soil–water tension over the whole first-irrigation period (day 4 to 34), but no such difference was found at 10 cm depth.

**Table 2.** *Tensiometer readings from the first to the second irrigation for two treatments<sup>1</sup>, Debre Zeit, Ethiopia, 6 October – 4 November 1987.*

Period (days <sup>3</sup> )	Number of observations	Soil–water tension (kPa) at:					
		10 cm depth			30 cm depth		
		Mean <sup>2</sup>		Standard error	Mean <sup>2</sup>		Standard error
		T1	T2		T1	T2	
4–8	30	16.87a	9.70b	1.37	19.20a	9.57b	0.65
4–13	60	16.57a	11.00b	0.37	17.18a	10.70b	0.40
4–34	186	22.01a	20.28a	0.68	18.39a	18.39b	0.44

<sup>1</sup> T1 = no irrigation; T2 = irrigation at planting.

<sup>2</sup> For each depth, means with the same letter within a row do not differ significantly ( $P > 0.05$ ).

<sup>3</sup> Tensiometer readings started on the fourth day after the irrigation at planting, because during the first 3 days the soil was too wet to allow access to the tensiometers.

During the first 5 and 10 days after the second irrigation (treatment 3), plots with one irrigation had significantly ( $P < 0.05$ ) higher 10- and 30-cm soil–water tension than the control plots and plots with two irrigations (Table 3). Over the entire second-irrigation period, control plots had significantly ( $P < 0.05$ ) lower soil–water tension at both 10 and 30 cm depth than treatment-2 and treatment-3 plots.

During the first 5 and 10 days after the third irrigation (treatment 4), soil–water tension on control plots at both 10 and 30 cm depth was significantly ( $P < 0.05$ ) lower than on plots irrigated once or twice (Table 4). Control plots also had significantly lower 30-cm soil–water tension than treatment-4 plots in the first 10 days after irrigation, and over the entire period from third irrigation to harvest (day 70–17). *Soil moisture content.* This was usually, but not always, lowest on control plots and increased with the number of irrigations. During the germination period (6–13 October), the top 10 cm of plots with irrigation at planting had a higher soil moisture content (35%) than control plots (26%) (Figure 3). After the germination period, the difference between the control plots and those that were irrigated at planting decreased due to the increased water use on irrigated plots by emerging seedlings. Differences in soil moisture

content between treatments occurred at second irrigation and were greatest in the top 10 cm of soil.

**Table 3.** *Tensiometer readings from the second to the third irrigation for three treatments<sup>1</sup>, Debre Zeit, Ethiopia, 5 November–10 December 1987.*

Period (days)	Number of observations	Soil–water tension (kPa) at:							
		10 cm depth				30 cm depth			
		Mean <sup>2</sup>			Standard error	Mean <sup>2</sup>			Standard error
		T1	T2	T3		T1	T2	T3	
35–39	30	23.83b	30.87a	14.53c	2.34	14.50b	30.17a	12.50b	0.84
35–44	60	24.07b	33.28a	22.42b	1.53	17.30c	34.20a	22.32b	1.03
35–69	210	26.93b	45.66a	44.86a	0.89	22.13b	47.53a	47.53a	0.73

<sup>1</sup>T1 = no irrigation; T2 = irrigation at planting; T3 = irrigation at planting and 35 days after planting.

<sup>2</sup>For each depth, means with the same letter within a row do not differ significantly ( $P > 0.05$ ).

## Chickpea response

Chickpea did not germinate on plots without irrigation. The plants on plots irrigated only at planting were significantly ( $P < 0.05$ ) shorter than those growing on plots with two or three irrigations (Table 5), but they were bushier and had a more spreading habit.

Table 5 shows that 1000-seed weight was highest from plots irrigated only at planting. The difference in 1000-seed weight was significant ( $P < 0.05$ ) between treatments 2 and 4. Grain yield was significantly ( $P < 0.05$ ) lower on plots with three irrigations than on plots with one and two irrigations. No difference between treatments was observed with regard to straw yield.

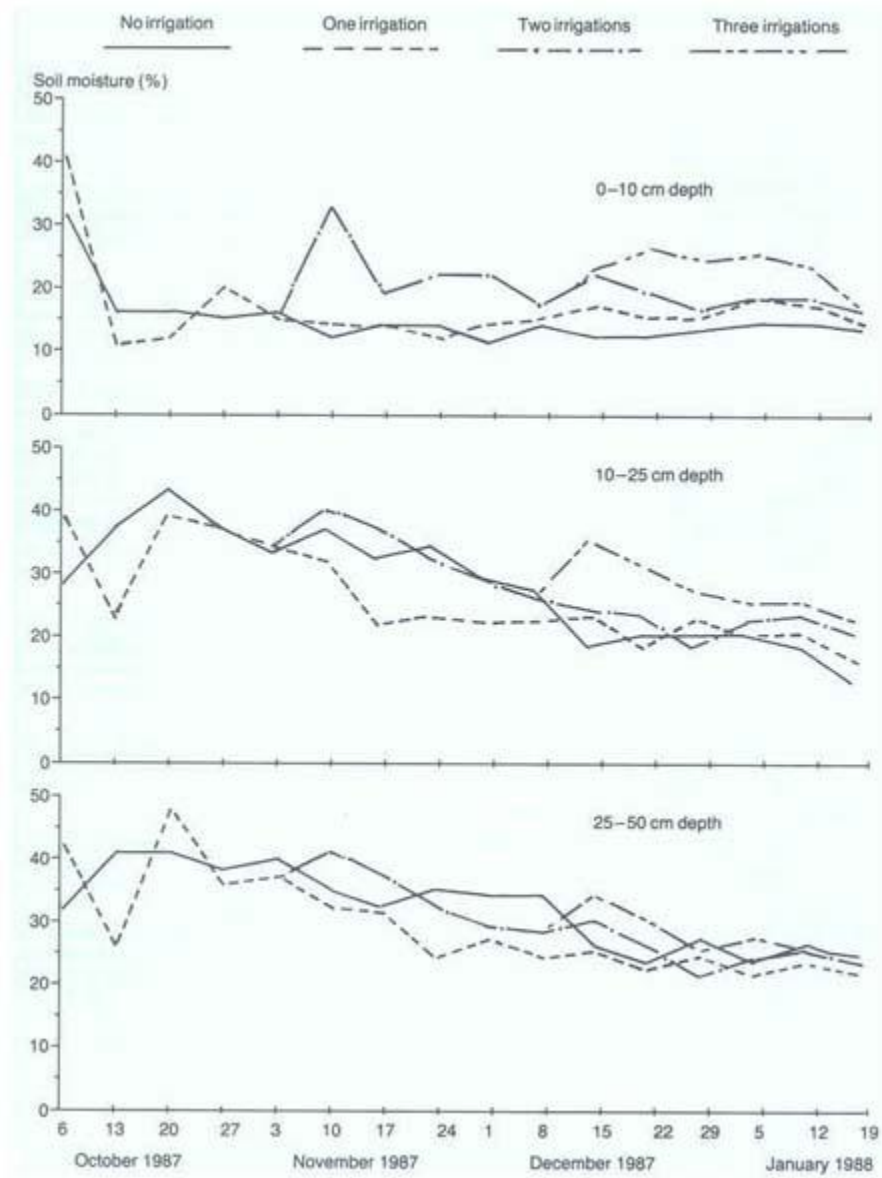
**Table 4.** *Tensiometer readings from the third irrigation to harvest for four treatments<sup>1</sup>, Debre Zeit, Ethiopia, 10 December 1987 – 28 January 1988.*

Period (days)	Number of observations	Soil–water tension (kPa) at:									
		10 cm depth					30 cm depth				
		Mean <sup>2</sup>				Standard error	Mean <sup>2</sup>				Standard error
		T1	T2	T3	T4		T1	T2	T3	T4	
70–74	30	25.87c	44.33b	51.50a	15.83d	1.72	17.93c	50.37b	62.17a	20.50c	1.72
70–79	60	29.55c	48.20b	58.88a	27.73c	1.33	19.63d	51.37b	64.45a	30.60c	1.17
70–117	288	35.59d	58.00b	63.62a	49.59c	0.69	26.26d	62.16b	67.57a	56.40c	0.56

<sup>1</sup>T1 = no irrigation; T2 = irrigation at planting and 35 days after planting; T4 = irrigation at planting and 35 and 70 days after planting.

<sup>2</sup> For each depth, means with the same letter in a row do not differ significantly ( $p > 0.05$ )

**Figure 3.** Soil moisture content at 0–10, 10–25 and 25–50 cm depth for four treatments, Debre Zeit, Ethiopia, 6 October 1987–19 January 1988.



## DISCUSSION

Seedbed preparation for the rainy-season crop (wheat) required 110 hours/ha, which is similar to the time taken by farmers to cultivate wheat fields with the traditional plough (*maresha*) (Getachew Asamenew et al, 1988). Wheat seed was covered in two passes with the broadbed maker, which together took 11 hours/ha. Using the *maresha*, the same operation would have required at least 25 hours/ha (Abiye Astatke and Matthews, 1984).

Bed reshaping and seed covering for the post-season crop (chickpea) required 41 hours/ha with the blade harrow. The total time spent on land preparation and seed covering for both the wheat and chickpea crops was 162 hours/ha, which is higher than the 103 hours/ha needed to prepare

land for chickpea alone with the traditional *maresha* (Gryseels and Anderson, 1983). However, considering that two crops were obtained instead of one, the extra labour input is well justified.

Between 70 and 80% of chickpea seeds germinated following the initial irrigation at planting, whereas on non-irrigated plots no seeds germinated. The International Crops Research Institute for the Semi-Arid Tropics reported that no chickpea cultivars germinated below 20% soil moisture content (ICRISAT, 1981). In the Debre Zeit study, germination did not occur even at 26% moisture content. This suggests that while there was sufficient moisture in the soil, not enough of it was available to start germination, because soil–water tension in the top 10 cm of soil was high (16.87 kPa). Irrigation at planting brought soil–water tension sufficiently low (9.70 kPa) to release enough water for seed germination.

**Table 5.** Average plant height, 1000–seed weight, and grain and straw yields of chickpea on plots subjected to three irrigation treatments<sup>1</sup>, Debre Zeit, Ethiopia, January 1988.

Variable	Number of observations	Mean <sup>2</sup>			Standard error
		T2	T3	T4	
Plant height (cm)	3	32.47a	42.10b	43.63	1.36
1000-seed weight (g)	3	111.73a	108.67ab	104.20b	1.25
Grain yield <sup>3</sup> (t/ha)	3	1.39a	1.38a	1.09b	0.07
Straw yield (t DM/ha)	3	2.16a	2.00a	1.92a	0.16

<sup>1</sup>T2 = irrigation at planting; T3 = irrigation at planting and 35 days after planting; T4 = irrigation at planting and 35 and 70 days after planting.

<sup>2</sup>Within rows means followed by the same letter do not differ significantly ( $P > 0.05$ ).

<sup>3</sup>Grain yield adjusted to 10% seed moisture.

During the first irrigation period, soil–water tension at 30 cm depth was higher on the control than on irrigated plots, but in later periods, the opposite was true. This is because chickpea plants on irrigated plots started using water from the lower layers for growth.

Plots with one and two irrigations had higher chickpea grain yields than plots irrigated three times. This is different from ICRISAT's (1980) finding that the grain yield of Kabuli chickpea increases with up to four irrigations. However, the Kabuli and Desi chickpea respond differently to irrigation (Saxena, 1980). Also, the amount of plant-available water stored by Vertisols in the Ethiopian highlands is high, ranging between 324 and 686 mm (Kamara and Haque, 1988). Thus, once the chickpea crop is established with the starter irrigation, the amount of residual moisture available in the soil is sufficient to satisfy its water demand for growth.

Plots irrigated only at planting had the highest straw yield, but the difference between treatments was not significant ( $P > 0.05$ ). Plants growing on plots irrigated twice and three times were taller than those growing on plots with one irrigation. The second and third irrigations may thus have stimulated further vegetative growth.



## CONCLUSIONS

Because of waterlogging, Vertisols in the Ethiopian highlands are left to lie fallow during most of the rainy season. Chickpea, roughpea and lentils are planted after the rains. They are heavily dependent on residual moisture, and their grain yield is low, not exceeding 1 t/ha.

The productivity of Vertisols in high rainfall areas can be increased by improved surface drainage. An example is the broadbed-and-furrow system which allows farmers to:

- Establish a first crop early in the growing season and obtain higher and more stable yields; and
- Harvest the first crop earlier and grow a second crop, using supplementary irrigation to stimulate germination.

Thus in the Debre Zeit area, where chickpea is traditionally produced and where off-season water is available, sequential cropping of cereals and legumes is not only technically viable, but also economically promising and ecologically desirable.

## ACKNOWLEDGEMENTS

We would like to thank Ato Aklilu Alemu for help with data collection, Ato Tadesse Tessema and Ato Taye Wolde Mariam for the smooth running of the experiments, and Miss Helena Airaksinen and Dr Erich Bruns for assistance in data analysis.

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